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ORIGINAL RESEARCH

RELIABILITY OF THREE MEASURES OF ANKLE DORSIFLEXION RANGE OF MOTION

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ABSTRACT

Purpose/Background: A variety of methods exist to measure ankle dorsiflexion range of motion (ROM). Few studies have examined the reliability of a novice rater. The purpose of this study was to determine the reliability of ankle ROM measurements using three different techniques in a novice rater.

Methods: Twenty healthy subjects (mean ± SD, age = 24 ± 3 years, height = 173.2 ± 8.1 cm, mass = 72.6 ± 15.2 kg) participated in this study. Ankle dorsiflexion ROM measures were obtained in a weight-bearing lunge position using a standard goniometer, digital inclinometer, and a tape measure using the distance-to-wall technique. All measures were obtained three times per side, with 10 minutes of rest between the first and second set of measures. Intrarater reliability was determined using an intraclass correlation coefficient ($ICC_{2,3}$) and associated 95% confidence intervals (CI). Standard error of measurement (SEM) and the minimal detectable change (MDC) for each measurement technique were also calculated.

Results: The within-session intrarater reliability ($ICC_{2,3}$) estimates for each measure are as follows: tape measure (right 0.98, left 0.99), digital inclinometer (right 0.96; left 0.97), and goniometer (right 0.85; left 0.96). The SEM for the tape measure method ranged from 0.4-0.6 cm and the MDC was between 1.1-1.5 cm. The SEM for the inclinometer was between 1.3-1.4° and the MDC was 3.7-3.8°. The SEM for the goniometer ranged from 1.8-2.8° with an MDC of 5.0-7.7°.

Conclusions: The results indicate that reliable measures of weight-bearing ankle dorsiflexion ROM can be obtained from a novice rater. All three techniques had good reliability and low measurement error, with the distance-to-wall technique using a tape measure and inclinometer methods resulting in higher reliability coefficients ($ICC_{2,3}$ = 0.96 to 0.99) and a lower SEM compared to the goniometer ($ICC_{2,3}$ = 0.85 to 0.96).

Key Words: goniometry, inclinometer, talocrural joint

Level of Evidence: 2b

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INTRODUCTION

There are a number of methods and tools available to measure ankle dorsiflexion range of motion (ROM) in both non-weight-bearing and weight-bearing positions. Weight-bearing measures are thought to more accurately reflect the available ROM during functional activities[1] such as walking, running, or stair ambulation, and may be more reliable (ICC = 0.93-0.96) than measures obtained in a non-weight-bearing position (ICC 0.32-0.72).[2] Most measurement techniques for ankle dorsiflexion ROM include the use of a standard goniometer,[3,4] an inclinometer,[5-8] or a tape measure,[1,9,10] and have varying levels of technical difficulty for the individual obtaining the measures.

The goniometer is inexpensive and commonly used in clinical environments, but also requires the greatest degree of technical proficiency, due to the necessity of aligning the axis with the joint fulcrum and positioning the two arms with established reference points.[3] The technical proficiency required to obtain measures of ROM with a goniometer may contribute to lower reported reliability values (ICC = 0.65-0.89) when compared to other measurement methods (ICC = 0.84-0.95).[11,12] Alternatively, an inclinometer may be used to measure ankle dorsiflexion ROM and only requires the rater to identify the tibial tuberosity for consistent inclinometer placement in a weight-bearing position[1,6,8] or to identify the base of the fifth metatarsal in a non-weight-bearing position.[5] The inclinometer may utilize a dial, bubble, or digital display to provide the angle of the slope relative to the ground. The digital display may potentially reduce recording errors, since the display provides a single numeric value versus requiring the rater to determine the location of the dial or bubble relative to the nearest tick-mark. The use of the inclinometer may improve reliability measures (ICC = 0.84 to 0.95) for novice raters, when compared to goniometer (ICC = 0.65 to 0.77) measures, in a non-weight-bearing position.[12] To the authors' knowledge, only one study[11] has compared novice and expert raters using a digital inclinometer versus a goniometer in a weight-bearing position; the study demonstrated similar reliability between techniques (ICC = 0.89 goniometer, 0.88 digital inclinometer). There is no consensus regarding the preference of using a goniometer or inclinometer for the measurement of ankle dorsiflexion ROM. Although the inclinometer is easy to use, the cost is usually higher than a standard goniometer.

An additional way to quantify ankle dorsiflexion ROM is with a tape measure.[1,13] This method utilizes the knee-to-wall principle, in which the subject performs a weight-bearing lunge. The patient places the test foot on a tape measure perpendicular to the wall and lunges forward so the knee touches the wall. The foot is moved away from the wall until the knee can only make slight contact with the wall while the foot remains flat on the ground. This position places the ankle in maximal dorsiflexion, and the distance from the great toe to the wall is measured in centimeters, with each centimeter corresponding to approximately 3.6° of ankle dorsiflexion.[1] This method is inexpensive, can be performed in a variety of settings, and does not require the technical proficiency associated with a goniometer or inclinometer. The tape measure method is also hypothesized to be more sensitive to change compared to measures of motion in degrees.[14]

Due to the different levels of technical proficiency required for each measurement method, some techniques may be better performed by raters with more experience, yielding greater measurement reliability.[11] Therefore, it is essential to determine which measurement techniques a novice rater would be able to perform reliably, and which techniques require additional practice and experience. Obtaining a better understanding of the reliability and error associated with each technique would provide valuable information for individuals who work with novice raters. Therefore, the purpose of this study was to compare the reliability of three different ankle ROM measurement techniques performed by a novice rater with no previous experience with any of the techniques.

METHODS

Experimental Approach

The approach was a pre/post-test design over a single testing session. A novice rater (fourth year exercise science student) performed all measurement techniques. The novice rater underwent approximately three hours of training with an experienced rater to standardize testing procedures and practiced these procedures on five volunteers prior to beginning the study.

Subjects

Twenty healthy adults (seven males, 13 females; mean ± SD, age = 24 ± 3years, height = 173.2 ± 8.1 cm, mass = 72.6 ± 15.2 kg) volunteered to participate in this study. Participants were recruited through university announcements and mass e-mails. Prior to enrollment, participants completed an Institutional Review Board-approved informed consent form and a health history form. Exclusion criteria included any lower extremity injury or surgery within the past six months.

Procedures

Maximal ankle dorsiflexion ROM was measured in a weight-bearing position (lunge) using a standard 7-inch, flat, clear plastic goniometer with 2° increments, a digital inclinometer with 1° increments (Acumar Single Digital Inclinometer; Lafayette Instrument Company, Lafayette, IN), and a metric tape measure with the ability to measure to 0.1 cm. All testing was completed with the participant barefoot. Three separate measures were obtained on the right and left ankles using each technique, with the initial side determined using a randomized chart. All measurements (goniometer, inclinometer, and tape measure) were obtained during the same session and, after obtaining the first set of measures, the participant rested for 10 minutes and the test sequence was repeated.

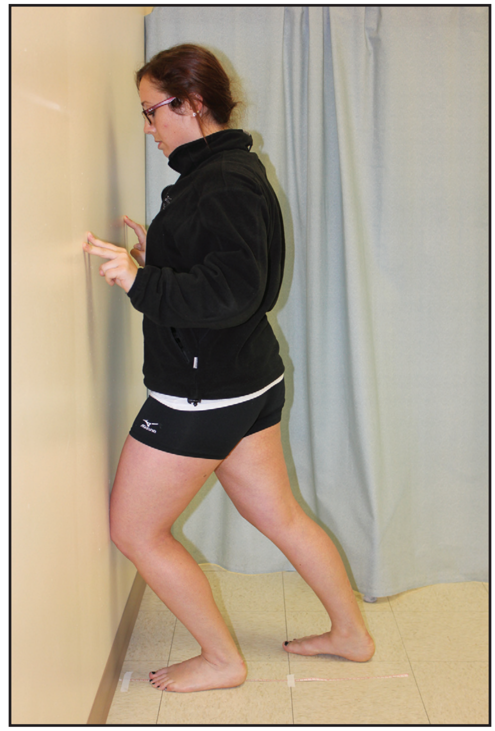

Figure 1. *Initial participant position for the weight-bearing lunge. The great toe is 10 cm from the wall and the knee is in line with the second toe.The participant is allowed to maintain contact with the wall using two fingers from each hand to maintain balance.*

Weight-Bearing Lunge

Ankle dorsiflexion ROM was measured using a weight-bearing lunge facing a wall (Figure 1). The weight-bearing lunge was performed in a standing position with the heel in contact with the ground, the knee in line with the second toe, and the great toe 10 cm away from the wall. Balance was maintained by allowing contact with the wall using two fingers from each hand. Participants were asked to lunge forward, directing their knees toward the wall (in line with the second toe) until their knees touched the wall. The foot was progressed away from the wall 1 cm at a time and the subject repeated the lunge until they were unable to touch the wall with their knee without lifting the heel from the ground. Once the knee was not able to touch the wall, the foot was progressed in smaller increments toward the wall until the knee made contact with the wall with the heel in contact with the ground.[9] This progression toward the wall allowed a measurement to be obtained to the nearest millimeter. If the participant was not able to touch their knee to the wall without lifting the heel from the ground at the initial 10 cm start position, the participant was asked to move his or her foot forward toward the wall 1 cm at a time until they could touch their knee to the wall while keeping the heel on the ground. At the point when the knee made contact with the wall, the foot was progressed in smaller increments away from the wall to allow a measure to be obtained to the nearest millimeter.[9] Maximal dorsiflexion ROM was defined as the maximum distance of the toe from the wall while maintaining contact between the wall and knee without lifting the heel.[1] Heel contact with the ground was monitored by the rater by lightly placing their fingers on the heel to feel for heel movement, while also visually examining the heel for movement. When the participant reached the final lunge position, a digital inclinometer (Figure 2) was placed at the tibial tuberosity and was used to measure the angle of the tibia relative to the ground. Prior to measurement for each subject, the goniometer was zeroed relative to the horizontal (versus the vertical default setting) by aligning the goniometer with a wall that was perpendicular to the floor (90°). This was done to ensure a consistent starting point across

Figure 2. *Inclinometer placement at the tibial tuberosity along the anterior tibial crest.*

Figure 3. *Goniometer aligned with floor (stable arm) and through the shaft of the fibula (mobile arm) by visually bisecting the lateral malleolus and the fibular head.*

all subjects. While the participant maintained his or her maximal dorsiflexion position, a standard goniometer (Figure 3) was aligned with floor (stable arm) and through the shaft of the fibula (mobile arm) by visually bisecting the lateral malleolus and the fibular head.[11] Finally, the rater recorded the distance of the great toe from the wall to the nearest 0.1 cm. Participants were allowed three practice trials per limb and completed three test trials per limb, with the average of each side used as the representative value for data analysis.

Statistical analysis

Descriptive data were calculated for each measurement technique, including means and standard deviations (SD) for each limb, as well as composite means (average of right and left sides). Intrarater reliability

Table 1. *Weight-Bearing Lunge Dorsiflexion Range of Motion Measurement Averages.*

Test	Mean±SD
Tape Measure	9.5 ± 3.1 cm
Digital Inclinometer	38.8 ± 5.2°
Goniometer	43.2 ± 5.8°

Averages were determined using data from each side (right and left) during trial 1

was determined using intraclass correlation coefficients ($ICC_{2,3}$) and associated 95% confidence intervals (CI). Standard error of measurement (SEM) ($SEM = SD\ \sqrt{1\text{-}ICC}$)[15] and the minimal detectable change (MDC) ($MDC = SEM * 1.96 * \sqrt{2}$)[15] for each measurement technique were also calculated. Briefly, the SEM reflects absolute measurement error (response stability),[15-17] and the MDC provides an objective threshold that can be used to determine whether values obtained are beyond measurement variability (i.e., smallest difference that can be accurately measured).[15,17] Reliability was defined as poor (ICC $<$ 0.50), moderate (ICC 0.50 to 0.75), or good (ICC $>$ 0.75) using previously established criteria.[17] All statistical analyses were performed with SPSS Version 19.0 (SPSS Inc., Chicago, IL).

RESULTS

The descriptive data ($X \pm SD$) for the composite measures of ankle dorsiflexion ROM are presented in Table 1. Descriptive statistics ($X \pm SD$) for the right and left side, as well as trial 1 and 2 for each technique, are presented in Table 2. Scatterplots (Figures 4-6) were constructed to compare measurement techniques using data obtained from both limbs during Trial 1. The within-session intrarater reliability ($ICC_{2,3}$) estimates ranged from 0.85 (goniometer) to 0.99 (tape measure) (Table 3). The SEM for the goniometer and inclinometer ranged from 1.3° to 2.8° with an MDC of 3.7° to 7.7°. The SEM for the tape measure method ranged from 0.4 cm to 0.6 cm (1.6° to 2.5°), and the MDC was between 1.1 cm and 1.5 cm (4.5° to 6.1°).

DISCUSSION

This was the first study to examine the reliability of three different techniques to measure ankle dorsiflexion ROM in a weight-bearing position using a novice

Table 2. *Dorsiflexion Range of Motion Measurements by Side and Trial. .*

Test	Side	Trial 1	Trial 2	*P* Value*
Tape Measure				
	Right	9.6 ± 2.9 cm	9.7 ± 2.9 cm	0.89
	Left	9.4 ± 3.3 cm	9.6 ± 3.4 cm	0.27
Digital inclinometer				
	Right	38.2 ± 4.5°	39.0 ± 4.7°	0.07
	Left	39.3 ± 5.8°	39.9 ± 5.5°	0.22
Goniometer				
	Right	43.4 ± 4.7°	43.9 ± 5.3°	0.56
	Left	43.1 ± 6.8°	44.1 ± 6.6°	0.07

*There were no significant differences between measures obtained during Trial 1 and Trial 2

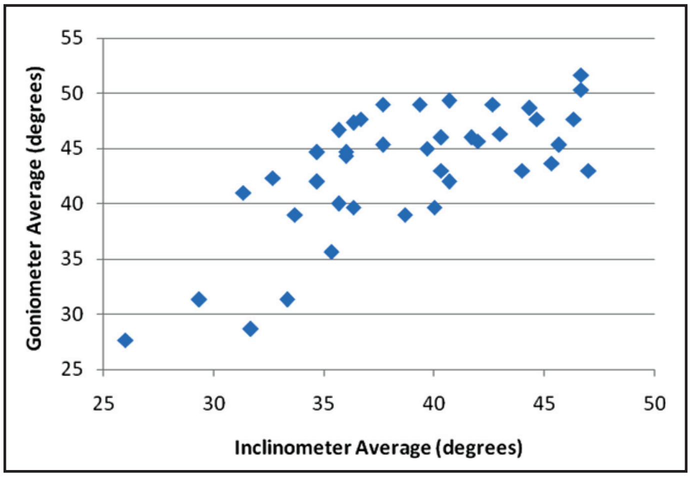

Figure 4. *Scatterplot for data from the goniometer and inclinometer measures.*

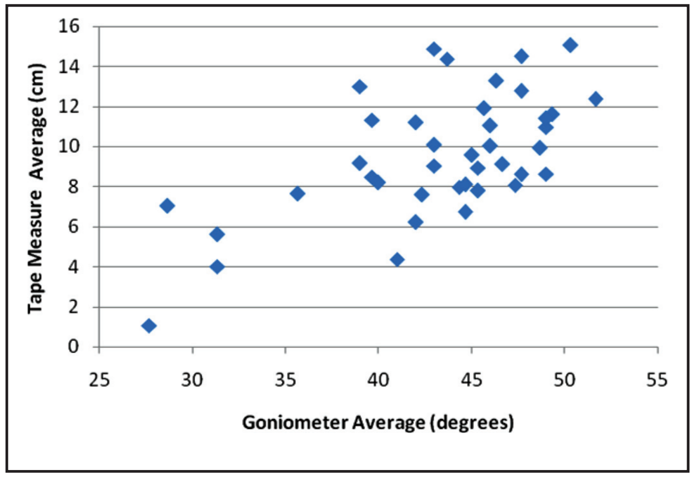

Figure 6. *Scatterplot for data from the tape measure and goniometer measures.*

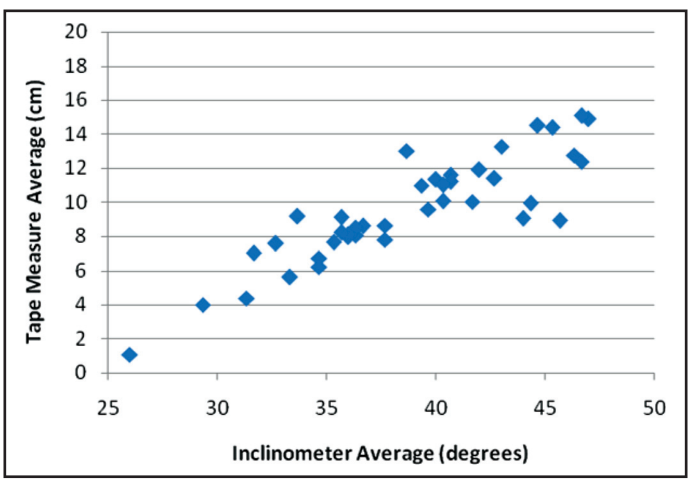

Figure 5. *Scatterplot for data from the tape measure and inclinometer measures.*

rater. The results showed good reliability (ICC$\geq$0.85) among all three techniques, with the distance-to-wall and inclinometer methods resulting in higher reliability coefficients (ICC = 0.96 to 0.99) compared to the goniometer (ICC = 0.85 to 0.96). In addition, all three measurement techniques resulted in low measurement error (SEM = 0.4-0.6cm with the tape measure, 1.8-2.8° with the goniometer, 1.3-1.4° with the digital inclinometer). These findings suggest that an individual with little training can obtain reliable measures of weight-bearing ankle dorsiflexion ROM utilizing a goniometer, inclinometer, or tape measure.

The reliability estimates obtained in this study (ICC > 0.88) are consistent with those obtained by other authors[1,2,4,5,9] who utilized raters of varying expe-

Table 3. *Intrarater Reliability ($ICC_{2,3}$) and Measurement Error for Dorsiflexion Range of Motion Measurements.*

	Right Side			Left Side		
Test	$ICC_{2,3}$ (95% CI)	SEM	MDC	$ICC_{2,3}$ (95% CI)	SEM	MDC
Tape Measure	0.98 (0.96,0.99)	0.6 cm	1.5 cm	0.99 (0.98,1.00)	0.4 cm	1.1 cm
Digital inclinometer	0.96 (0.89,0.98)	1.4°	3.8°	0.97 (0.93,0.99)	1.3°	3.7°
Goniometer	0.85 (0.62,0.94)	2.8°	7.7°	0.96 (0.91,0.99)	1.8°	5°

Abbreviations: ICC= interclass correlation coefficient; CI= confidence interval; SEM= standard error of measure; MDC= minimal detectable change.

rience. Previous studies[1,11] have utilized novice raters and compared them to more experienced raters, but have not determined which technique yields the best reliability for a novice rater. Bennell et al.[1] used a second year physical therapy student as their novice rater and found good reliability (0.99 CI: 0.97-0.99) when measuring weight-bearing ankle dorsiflexion with a digital inclinometer and the distance-from-wall measurements 0.97 (0.90-0.99). Munteaunu et al.[11] used a senior undergraduate student as their novice rater and found good reliability (ICC = 0.77) for ankle dorsiflexion ROM measures in a weight-bearing position with the knee extended using a digital inclinometer, but these reliability estimates were slightly lower than reliability among experienced raters (ICC = 0.88). The results of this study demonstrate good reliability (ICC$\geq$0.85) among all three techniques, with the distance-to-wall and inclinometer methods resulting in higher reliability coefficients (ICC = 0.96 to 0.99) compared to the goniometer (ICC = 0.85 to 0.96).

The methods outlined in this study for measuring ankle dorsiflexion ROM vary slightly from methods previously proposed by other authors.[1,5,7,10,11] It has been suggested that subtalar and foot position, specifically pronation, may allow the ankle to achieve greater angles of dorsiflexion ROM.[18,19] Although the authors did not specifically place the foot in a subtalar neutral position or utilize a small wedge placed under the medial aspect of the foot to maintain a more neutral position of the subtalar joint,[20,21] we did have the subject progress his or her knee in an anterior direction (toward the wall) in line with the second toe.[10,22] Alternatively, a vertical line, perpendicular to the tape measure, can be drawn on the wall[1] and may serve as a visual target for the knee to progress toward the wall and to maintain foot alignment.

A second methodological difference was the placement of the digital inclinometer. The tibial tuberosity,[6] 15 cm distal to the tibial tuberosity,[1] a mid-point between the tibial tuberosity and the talocrural joint,[11] and the distal lateral aspect of the tibia[7] have all been used as anatomical landmarks for placement of the inclinometer. Since the measure of ankle dorsiflexion ROM obtained is the angle of the tibia relative to the ground (horizontal), it is possible that any point along the tibia may be used to obtain a measure of ankle dorsiflexion ROM. In this study, the authors utilized the tibial tuberosity as a bony landmark for placement of the inclinometer[6] because we felt that this location could be consistently and easily identified by a novice examiner. Identification of a single bony landmark may also be more desirable for clinicians versus identifying a bony landmark and then measuring to a distant site, such as 15 cm distally, then placing the inclinometer on the tibia.[1] Although the tibial tuberosity is not an entirely flat surface, the foot of the inclinometer was able to make contact with this landmark, while the other foot of the inclinometer made contact with the tibial crest.

When performing a weight-bearing lunge near a wall, the placement of a digital inclinometer on the tibial tuberosity may leave little clearance between the wall and inclinometer. Although this was not an issue in this study, the authors suggest that, when utilizing an inclinometer, the weight-bearing lunge be performed away from a wall.[6] While a number of anatomical locations have been utilized for placement of the inclinometer, the optimal placement has not been determined. Despite the fact the methodology utilized in this study varies slightly from previous studies,[1,5,7,10,11] it should be noted that all measurement techniques demonstrated good reliability between the first and second trials when performed by a novice rater.

The composite mean for the inclinometer measurement technique (38.8° ± 5.2°; Table 1) is consistent with previously reported normative values (30°-50°) for healthy individuals.[1,5,23] The ROM value for the tape measure method (9.5 cm) expressed in centimeters is lower than what has previously been reported (11-14 cm),[1,2,9] but the MDC values (1.1 to 1.5 cm) derived in this study are consistent with the results of previous studies. The composite measure of ankle dorsiflexion obtained using the goniometer in the current study was 43.2°, which is considerably higher compared the findings of Johnson et al.[24] and Burns and Crosbie,[23] who both reported values of 32° for healthy subjects. The age ranges in the previous studies (19-30 years)[23,24] were similar to the age range for our subjects (20-34 years). The differences in the results for the goniometer in the current study and those of Johnson et al.[24] and Burns and Crosbie[23] may be due to slight differences in control of foot position during testing. In the current investigation, we did not attempt to control for foot position (subtalar neutral), whereas previous studies using goniometers have specifically controlled for subtalar joint position.[18,21,23,24]

Although all three measurements in this study were obtained almost simultaneously, there were slight differences in the point estimates when using the goniometer and inclinometer. Differences may have been due to the anatomical reference points utilized for each measure.[25] In this study, the mobile arm of the goniometer was aligned with the fibular head[3,4] and the digital inclinometer was aligned with the tibial tuberosity.[6,8] The difference between inclinometer and goniometer measures was slightly less than 5° (inclinometer 38.8°; goniometer 43.2°). Utilizing the tibial tuberosity has been shown to result in ROM measures that are approximately 5° greater than using the fibular head as an anatomical landmark.[25] Our results were actually 5° greater for the inclinometer when compared to the goniometer. It is not known whether the differences between the goniometer and inclinometer measures are due to differences in methods used to obtain ROM measures,[25] or potentially due to a systematic rater error, such as consistent goniometer misalignment. Regardless, both goniometer and inclinometer measures are within the previously reported normative values (30-50°).[1,5,23] The MDC for inclinometer measures was 3.7° and 3.8° for the left and right ankle, respectively, and is within the range (1.5° and 6.4°) reported in previous studies.[5,7] The MDC for the tape measure method was 1.1-1.5 cm, which is also consistent with values (0.4-1.4 cm) reported in previous studies.[1,9]

Although the weight-bearing lunge is commonly used to determine dorsiflexion ankle ROM,[1,4-10] there is no universal agreement regarding which measurement device (goniometer, inclinometer, tape measure) is most preferred. The results of this study indicated that the digital inclinometer was more sensitive to changes in motion than the goniometer (inclinometer MDC = 3.8° versus goniometer MDC = 7.7°). Differences between the tape measure and digital inclinometer are not as evident since different units of measure are utilized (centimeters versus degrees). Previous data[1] has been used to extrapolate a conversion equation in which 1 cm of distance from the toe to the wall roughly equals 3.6° of ankle dorsiflexion ROM.[1] However, the results of this study indicate that every 1 cm of distance equals 4.1° of dorsiflexion ROM. It is possible that a simple conversion equation may not be possible, and future studies should determine whether a more accurate conversion equation is possible. While the reliability estimates and absolute measures of ROM between the three techniques were consistent with previous research, the use of a single novice rater performing three specific techniques was unique to this study.

Measurement techniques in this study were obtained exclusively in a weight-bearing position, and measures of weight-bearing ROM may not be possible with some clinical populations. Reliability for measures obtained in a non-weight-bearing position have been shown to range from poor (ICC = 0.32) to good (ICC = 0.97),[2,24,26-30] but it has been suggested by Venturini et al.[2] that measures in a weight-bearing position may provide greater reliability estimates (non-weight-bearing ICC = 0.32-0.72 ; weight-bearing ICC = 0.93-0.96). Although ROM determined in a weight-bearing position may be more indicative of the available functional dorsiflexion ROM,[1] it does not measure motion at a specific joint (talocrural, subtalar, tarsal). We did not attempt to control for pronation/supination, which may have adversely influenced the available dorsiflexion ROM.[18,21] If it is necessary to determine ROM at a specific joint, clinicians and researchers should attempt to restrict motions, such as pronation, by using a towel,[8] or measure ROM in a non-weight-bearing position.

Limitations to this study include a small sample size of 20 participants, all of whom were healthy and between the ages of 20 and 34 years. All of the subjects tested were free of ankle or lower extremity injury, which could have aided the ease of results. Therefore, it is not possible to generalize our findings to individuals outside of this age range or to individuals with joint pathology. Further research is needed across a broad age range (youth to geriatric) and on individuals with a history of joint pathology (i.e., ankle sprain).

Other limitations to the study are that only one novice rater was used, and that the order of measurement techniques was not randomized. Therefore, it is possible that the rater became more proficient with the measurement techniques as the study progressed. In addition, since the rater was not blinded to the measurements, it is possible that his or her knowledge of the initial values may have influenced subsequent measures. The authors felt that, since the three measurement techniques require the rater to make a judgment regarding the number of degrees indicated by the goniometer or inclinometer, blinding the rater to these measures would have limited the generalizability of the study. Future studies may be warranted to determine whether a learning curve is present, and may consider blinding the assessor. Finally, this study did not investigate the reliability of an experienced rater. Although previous studies have provided reliability estimates ranging from 0.88 to 0.99,[1,5,7,9,11] for experienced raters utilizing these measurement techniques, additional research may provide a better understanding of the relative differences in reliability between novice and experienced raters.

CONCLUSION

The results of this study indicated that a novice rater, with no prior experience using three different ankle ROM measurement techniques, can obtain reliable estimates of ankle dorsiflexion ROM in healthy individuals using a goniometer, digital inclinometer, or tape measure method. The measurements were obtained using a standardized protocol, which can be easily replicated in a clinical or research environment, and the SEM and MDC scores for the three techniques were low, which provides some level of confidence that changes in ROM following intervention are beyond that of measurement error. The reliability coefficients for the digital inclinometer and tape measure techniques were higher ($ICC_{2,3}$ = 0.96 to 0.99) compared to the goniometer ($ICC_{2,3}$ = 0.85 to 0.96), and the inclinometer resulted in the lowest MDC; therefore, the inclinometer may be preferred over the tape measure and goniometer techniques, particularly when measuring changes in ROM before and after injury or intervention.

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